COMMON SUPPORT EQUIPMENT
AND ITS IMPACT ON AIRCRAFT AVAILABILITY

THESIS

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THESIS

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics and Supply Chain Management

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March 2017

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Abstract

The ability of military aircraft maintenance personnel to prepare aircraft for flight depends not only on the technical ability and availability of replacement parts, but also on access to serviceable support equipment. While the general relationship between support equipment failures and aircraft availability is understood, the struggle to quantify that relationship makes targeted support equipment replacement or quantity authorization increases difficult. Tight budgets and aging equipment further complicate the task of keeping serviceable support equipment assets in the hands of maintainers. We identify key pieces of support equipment which may affect aircraft availability and other metrics and investigate the associated relationships in a case study of the F-16 aircraft.

Acknowledgments

I would like to thank my wife for all of her love and support during my time at AFIT. Taking care of two kids and ensuring that they make it to every school appointment and extra curricular activity while simultaneously earning a Bachelor of Science is no easy feat. You managed all of that while giving me the time I needed to complete numerous assignments and projects and for that I am grateful. I also want to thank my son and daughter who gave me study time when I needed it but also let me know when it was time for play. You have both grown so much during this time and I am proud of you every day. Additionally, this thesis would not have been possible without the coordination and hospitality of each case study location. There are far too many individuals to name but for everyone who helped make my visit successful I thank you. Finally, I would like to thank my advisor (Dr. Johnson/AFIT), sponsor (AFMC/A4M & A4P Col Fike), and my AFMC/A4M SME (CMSgt Hesterman). I understand the time that went into making this project complete and appreciate all the guidance, encouragement, and candor throughout the entire year.

Jason M. Leighton

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I. Introduction

Background

Common Support Equipment (CSE) used to facilitate ground maintenance on a wide array of aircraft is aging and becoming less reliable. The decrease in reliability coupled with a reduction in the number of available CSE assets is and will continue to negatively affect aircraft availability rates (Havlicek, 1997). Therefore, the purpose of this study is to examine the impacts that degrading CSE reliability and availability have on required maintenance activities and Aircraft Availability (AA).

AA is the universal standard for overall unit readiness and effectiveness (Raney, Young, & Golden, 2009). Of the two metrics used to calculate AA, Not-Mission Capable Maintenance (NMCM) captures maintenance factors such as repair actions/hours, maintenance downtime/reliability, and 8-hour fix rates (Oliver, Johnson, White III, & Arostegui, 2001). Each of these factors can be impacted by CSE due to its inherent use in maintenance activities, but while the requirement for CSE has not diminished, the funding to replace outdated equipment falls far short of annual requests. For example, the 2013 request for CSE funding, which was aimed at maintaining and updating a fleet of 214 million individual items, was funded $1.24B short (Sprague, 2014). One reason for the annual shortfall is an inability for CSE managers to show a quantifiable link between CSE and the AA. Justification of funding could be better articulated and the worldwide fleet of CSE could be better updated, increased, or optimized if such a relationship could be found. This research was scoped and developed in partnership with its sponsor, AFMC/A4M & A4P

Problem Statement

The thesis of this research is that AA is being negatively impacted by a CSE fleet which has become less reliable than designed even though the current number of CSE assets available are above the authorized levels.

Research Objectives and Questions

Quantifying the relationship between CSE and AA will require an examination of equipment availability and reliability levels and a comparison of those levels to AA rated during the same time period. Working with this research's sponsor, the following research questions were developed to explore specific facets of the CSE/AA relationship.

1. What impact does common support equipment (CSE) have on Aircraft Availability?
2. What statistical relationship best describes how CSE authorizations and levels affect aircraft availability?
3. What LIMS-EV Equipment View shortfalls limit CSE focus and management?
4. What maintenance work-arounds mask the impact of CSE on aircraft availability?

Research Focus

This research will focus on the reliability and availability of specific CSE. Additionally, this research will focus on AA rates and how they are impacted by CSE. The final focus will be on identifying ways in which reorganizing, redistributing, or adjusting authorizations of CSE can improve AA.

Methodology

A case study methodology is utilized for this research with interviews necessary for the collection of qualitative data. This method was chosen, because it provides a broad approach to examine the phenomenon associated with a number of unknown relationships in a dynamic environment such as flightline and back-shop maintenance operations. A multiple-case study will be performed consisting of six separate F-16 bases (Shaw, Luke, Nellis, Hill, Eielson, and Holloman Air Force Base (AFB), with a cross-case study being performed at the end. The six bases were selected in order to maximize the variability between geographic location and mission priorities for the purpose of a more comprehensive analysis of the stateside F-16 fleet. The case study at each location will examine the flying mission, aircraft breakage rate, AA, support equipment authorizations and quantity on hand, Mean Time Between Failure for powered CSE, demand for CSE, and other factors which are sure to present themselves on location.

Once the case studies are performed and reports are generated, a cross case analysis will be performed to identify specific support equipment assets for inclusion in the quantitative portion of this study. The quantitative phase of this study will examine historical equipment and aircraft data for the purpose of uncovering any quantifiable relationship between the two.

Assumptions/Limitations

In any research it is necessary to make simplifying assumptions in order to focus attention on the variables of interest. In this research, the first assumption was that the data collected and the analysis performed on the specific aircraft maintenance unit samples are representative of the greater whole of similar aircraft. Additionally, it is assumed that CSE will have a greater impact on AA for those aircraft systems which are not able to be tested, powered on, or otherwise operated by an internal capability of the aircraft during maintenance. For example, an aircraft with an Auxiliary Power Unit (APU) will be less reliant on a function CSE pool for items such as ground power carts, hydraulic test carts, or other similar ground support equipment due to its ability to apply power to those systems through internal power systems.

In addition to the assumptions made, this research had limitations which were necessary due to data, time, and financial limitations. Because of those limitations, every piece of support equipment could not be examined thoroughly enough to identify its impact on Aircraft Availability. In addition, this study is limited to six specific F-16 maintenance units in order to draw assumptions about the larger F-16 fleet and it is also limited by the time of year, specific missions, and geographic locations of the units studied. Finally, breakage rates of both aircraft and CSE are sure to fluctuate with any variation in these attributes and this study therefore cannot seek to explore the multitude of conditions under which the F-16 will operate.

Implications

The implications of this research is in the ability for the Air Force to more accurately assess its CSE needs as they relate to AA and the greater mission. This study aims to uncover the relationship between availability of CSE and the availability of aircraft as well as to quantify that relationship such that known CSE pool sizes and reliability rates can be used to predict the availability of aircraft.

II. Literature Review

Chapter Overview

The review of literature for this study focuses on AA as well as CSE to include Aerospace Ground Equipment (AGE). The AA metric will be broken down to show the variables which are used to calculate this primary measure of mission readiness. Additionally, literature which focuses on the AA metric will be discussed to identify a lack of focus on Not-Mission Capable for Maintenance (NMCM) the metric where CSE has the greatest impact.

Aircraft Availability

As the primary metric for measuring fleet health and mission readiness, AA is the go-to measurement when determining how a fighter squadron or wing is prepared to accomplish their mission. Like many high level metrics, AA is comprised of many lower level metrics which are each calculated using different measurements (see Figure 1). The 2009 Maintenance Metrics Handbook states that,

> The MC rate will no longer be the yard stick for measuring the health of the fleet. Instead maintenance managers will utilize aircraft availability which takes more than just MC rate into account. Not-Mission Capable Both (NMCB), Not-Mission Capable Supply (NMCS), (NMCM), unit possessed not reported (UPNR), and depot times will be used when calculation the overall health of the fleet and aircraft availability. (Rainey et al., 2009)

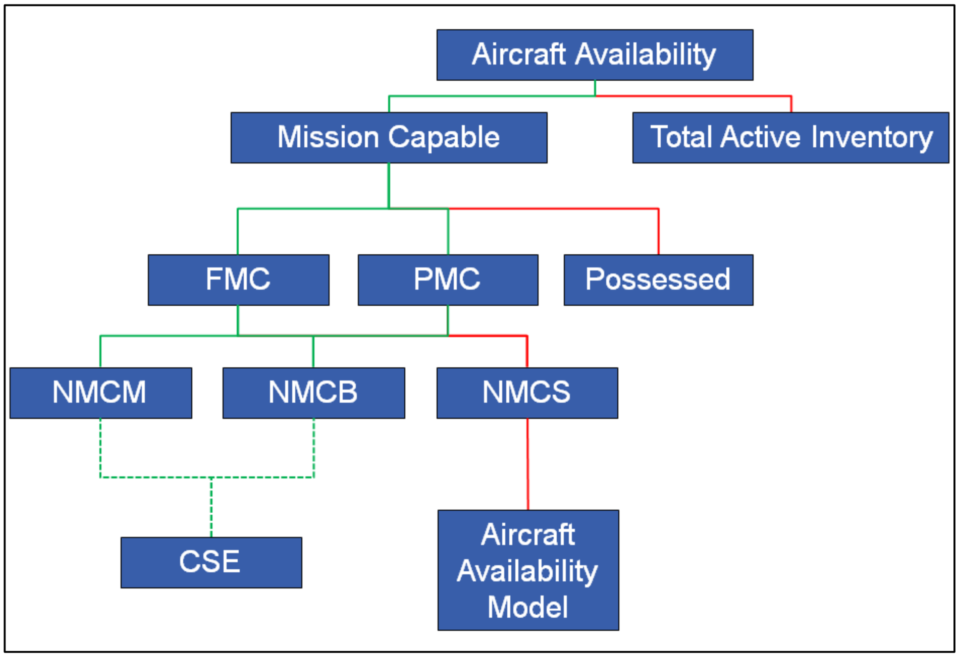


Figure 1: Aircraft Availability Metric Breakdown (USAF/A4LM, 2009)

The Aircraft Availability metric is calculated using the following formula:

$$Aircraft\ Availability\ Rate = \frac{MC\ hours}{TAI\ Hours} x100$$

Technical Order 00-20-2 defines Mission Capable (MC) hours as the following, "Mission Capable (MC) hours are the sum of MC hours in the following Possession Purpose Codes (PPCs): CA…." (Department of the Air Force, 2009). It further defines Total Active Inventory (TIA) as "hours [that] are the possessed hours of the following PPCs: BJ…." (Department of the Air Force, 2009).

The Mission Capable Rate metric is calculated using the following formula:

$$MC\ Rate = \frac{FMC\ Hours + PMC\ Hours}{Possessed\ Hours} x100$$

Technical Order 00-20-2 defines Fully Mission Capable (FMC), Partially Mission Capable (PMC), and possessed hours as "the sum of hours in the following PPCs: CA…." (Department of the Air Force, 2009)

Both FMC and PMC rates are calculated using a similar formula, with the numerator being substituted for FMC hours or PMC hours.

$$FMC\ Rate = \frac{FMC\ Hours}{Possessed\ Hours} x100$$

.

$$PMC\ Rate = \frac{PMC\ Hours}{Possessed\ Hours} x100$$

FMC and PMC rates are calculated using PMC and FMC hours which are a function of the metric Not-Mission Capable Maintenance (NMCM), Not-Mission Capable Supply (NMCS) and Not-Mission Capable Both (NMCB). This metric is generated at the lowest level by way of aircraft statusing from the flightline with NMCM and NMCS being the core measurements. NMCM is the level at which this study will focus on as it is where CSE has the most direct impact on AA.

As referenced above, the ability for aircraft to fly, fight and win is enabled by numerous factors which aggregate to form the metrics of NMCS and NMCM, the latter of which captures an aircraft which is not FMC due to non-supply related issues. The NMCM metric is further broken down into one of five sub-designations all with generic definitions as to the state of maintenance activities. While any of these sub-designations could be used to account for an inability to perform maintenance due to unavailable CSE; a specific code to capture such a gap in equipment is not currently available. Such a code would give greater flexibility to statusing of aircraft while allowing for an audit trail of equipment's impact on the repair of aircraft. NMCM is a lagging metric which represents the "percentage of unit possessed (reported) aircraft unable to meet primary assigned missions for maintenance reasons (includes NMCM and NMCB) Desired Trend (down)" (Raney, Young, & Golden, 2009) and is the most common and useful metric for determining if maintenance is being performed quickly and accurately (Raney, Young, & Golden, 2009). The problem with NMCM being the lowest level metric is that although it is used to determine the speed and accuracy of maintenance, no further explanation as to why the aircraft is statused as NMCM is required. The reason is hypothesized that maintenance personnel are in the process of performing repairs, that the aircraft is unavailable for maintenance due to its physical location or another factor limiting maintenance personnel from accessing it, or as is the hypothesis of this study, that maintenance is unable to be performed due to the unavailability of necessary support equipment.

Factors Other Than Funding and Their Effects on AA

While funding is often pointed to as a key indicator of AA or MC, it should not be the only consideration (Chapa, 2013) (Fry, 2010) (Oliver, Johnson, White III, &

Arostegui, 2001) (Theiss, 2013). For example, equipment has been examined to determine its impact on AA, but that look has largely been relegated to AGE which, although it is a large part of CSE, it's not the only equipment required to maintain a fleet of aircraft (Havlicek, 1997) (Kaya, 2002).

With the lack of funding and focus on equipment outside of AGE, leaders must be more aware of what factors influence AA so that a more meaningful assessment for targeted improvement areas can be made (Fry, 2010). As shown in Figure 2, 53 factors have been shown as potentially impactful to MC rates; the predecessor to AA (Oliver, Johnson, White III, & Arostegui, 2001).

Personnel	**Environment**	**Reliability & Maintainability**	**Funding**	**Aircraft Operations**	**Logistics Operations**
Personnel assigned or authorized	OPSTEMPO factors	TNMCM hours	Replenishment spares funding	Aircraft utilization Rates	TNMCS hours
Personnel in each skill-level (1,3,5,7,9 and 0)	PERSTEMPO factors	Maintenance downtime/reliability	Repair funding	Possessed hours	Base repair cycle time
F-16 maintenance personnel in various Air Force specialty codes (AFSC)	Policy changes	Code 3 breaks	Contractor logistics support funding	Flying hours	Level of serviceable inventory
F-16 maintenance personnel by skill-level per AFSC	Contingencies	8-hour fix rate	Mission support funding	Sorties	Level of unserviceable inventory
F-16 maintenance personnel by grade per AFSC	Vanishing Vendors	Repairable item failures	O&M funding	Flying scheduling effectiveness	Supply reliability
Retention rates for F-16 maintenance personnel	Weather	Cannibalization hours/actions	Initial spares funding	Type mission (DACT, CAP, and so forth)	Supply downtime
Personnel per aircraft ratios	Aircraft age	Repair actions/hours	Acquisition logistics funding	Over-Gs	Depot repair cycle time
Maintenance officers assigned or authorized	Aircraft mission (training, test, combat)	Maintenance man-hours		Airframe hours	Maintenance scheduling effectiveness

Figure 2: Factors Impacting MC Rates

Factors may include personnel, environment, reliability/maintainability, funding, aircraft operations, and logistics operations; all which need to be effectively managed

(Oliver, Johnson, White III, & Arostegui, 2001). Additionally, higher level variables such as mission type, primary base, Major Command (MAJCOM), aircraft age, mission priority and spare parts availability from a supply standpoint are other areas where a diminishing CSE pools may impact (Theiss, 2013) (Oliver, Johnson, White III, & Arostegui, 2001).

Support Equipment

Support equipment consist of all equipment (mobile or fixed) that is not inherently part of the primary weapon system, but is required to support the operation and maintenance of the system. The support equipment includes associated multiuse end items, ground handling and maintenance equipment, tools metrology, calibration equipment, test equipment and automatic test equipment. It also includes the labor for the support equipment itself (Defense Acquisition University, 2013). One of the most ubiquitous subsets of CSE is AGE which is managed by specialists from a pooled asset sense. AGE personnel maintain and repair a number of generators, test stands, maintenance platforms, heating and cooling units, munitions handling equipment, and many other assets. These assets are used in various maintenance activities and are integral to aircraft maintenance personnel’s ability to produce aircraft in flight ready conditions. While nowhere near as abundant, testing equipment used to functionally check various systems of an aircraft are just as important to the maintainability of a fleet. This facet of support equipment includes testers used to check cabin pressure, test radar warning systems, simulate altitude, check operability of weapons systems, and many other checks necessary to prepare an aircraft for flight. The third category of support equipment can be categorized as accessories/fixtures which are used during removal or installation of laptops, cables, or other calibration equipment used on the aircraft.

Equipment Inventory Levels

Equipment level authorizations begin with a unit's tasked Unit Type Codes (UTCs) which outline potential capabilities or specific missions that the unit may be tasked to provide (Department of the Air Force, 2012). From that UTC, Allowance Standards are built which identify the amount and type of equipment required for that specific mission (Department of the Air Force, 2012). These authorizations are combined to show the total number of each asset allowed for the unit which they then requisition through the supply system. This number represents the maximum allowable number of assets however, not necessarily the number which they will receive. Since there is a finite amount of support equipment available in the supply system, units typically operate at a level lower than that which they are authorized.

Shared Resources

To further complicate the business of aircraft maintenance is the nature of ownership for many support equipment pieces. While many assets such as testers, fixtures and other small pieces of equipment fall under the maintenance unit's span of control, larger assets are typically pooled together as a common shared resource across the wing. Without direct ownership over the assets, a potential exists whereby competing maintenance units could exhaust resources available to the overall wing by maximizing their individual utility; a theory known as "The Tragedy of the Commons" (Ostram,

2008) (Wade, 1987). For example, a maintenance squadron consisting of three maintenance units is assigned six hydraulic test stands for common use. One of those squadrons utilizes four of the stands concurrently for maintenance activates while the remaining two test stands are unserviceable due for repair. This scenario leaves the remaining two maintenance units without the ability to use a test stand for their own maintenance actions, thereby delaying their ability to return broken aircraft to a ready status. If the same six assets were not managed through a common pool but were instead issued out to each squadron then the likelihood of one squadron using all of the resources would be greatly diminished.

III. Methodology

Overview

The goal of this research is to explore the relationship between CSE and AA to determine if the two are quantitatively linked. To do this, a mixed methods approach was undertaken to explore each side. A case study was performed to qualitatively examine the problem to identify potential support equipment assets for further study. Next, a quantitative examination of historical data for the specific pieces of support equipment identified during the case study was performed. The first section of this chapter will explain case study methodology and its purpose in this research while the second section addresses the quantitative analysis of data pertaining to specific support equipment assets.

Scope

The scope of this research was determined in conjunction with its sponsor, AFMC/A4. The F-16 was chosen due to the maturity of the aircraft, a large number of active duty stateside locations, and an abundance of aircraft data. The selected locations for the case study were all six active duty stateside F-16 bases: Shaw AFB, Luke AFB, Holloman AFB, Nellis AFB, Hill AFB, and Eielson AFB. Although an abundance of aircraft specific data was available, similar data for equipment was not. The case study was therefore chosen to narrow down the large number of support equipment items available into a short list of items for study.

Case Study

The purpose of the case study was to narrow down the field of available support equipment for statistical analysis. When this study was first undertaken, the concept of Common Support Equipment was used in a broad sense so as not to limit literature research.

Interviews

Instead of beginning the case study methodology with a massive list of assets, a blank slate approach was taken with inputs from subject matter experts (SME). These inputs included the identification of specific pieces of equipment that the SME felt had the greatest impact, were unreliable, were difficult to obtain, or had a high degree of scarcity. These SMEs were chosen based on their experience with the aircraft, as well as their position and job description. The list included Aircraft Maintenance Unit Officers in Charge, Aircraft Production Superintendents, Aircraft Expeditors, Equipment Custodians (support section personnel), AGE Production Superintendents, AGE Expeditor/Floor Leads, Precision Measurement Equipment Laboratory (PMEL) Flight Chiefs, and Backshop Repair Leads. The interviewees were asked a series of four questions designed to uncover which support equipment items were most difficult to get, hardest to keep in service, or least reliable. The following questions were asked:

1) Which CSE items are most scarce/highly sought after?
2) Which CSE items are least reliable?
3) How confident are you that these CSE items will work when used?
4) How does sharing these assets affect your ability to use them?

5) What would you do if this piece of equipment was not available?

6) How often do you call for/need each piece of equipment?

7) What pieces of CSE overlap in their purposes?

8) Which one is the primary and which is the secondary?

9) How does CSE affect NMCM?

10) How would a classification of NMCM-CSE effect your reporting?

11) How do you track CSE status?

12) How could CSE status tracking be improved?

13) What database do you input tracking data into?

14) What are your current levels of CSE compared to your authorizations?

The interviewees were not asked to give any specific number of responses or any specific category of equipment. From these interviews, a response matrix was produced which painted a picture of the assets needing a quantitative examination.

Selecting Equipment

Once both the case study analysis and cross case analysis was performed, a total of 51 equipment items were identified by at least one to as many as 17 interviewees. From this list, six individual pieces of support equipment were identified as potentially having the highest likelihood of affecting AA with 22.2 percent to 37.8 percent of interviewees identifying each asset as being impactful to maintenance, difficult to obtain, scarce, or unreliable. Those pieces of equipment are the Environmental Control System Test Set (ECS Tester), Joint Services Electronic Combat Systems Tester (JSECT Tester), TTU-205 Pressure-Temperature Tester (205 Tester), A/M32A-60 Generator (-60), Self-

Generating Nitrogen Cart (SGNSC), and the Hydraulic Test Stand (MULE). The AGE assets were not able to be included in this study however as the database used to track their maintenance, Integrated Maintenance Data System (IMDS), is unable to produce reports of maintenance activities greater than 90 days in the past. IMDS only captures this information if the maintainer who entered the data at the time of the maintenance action elected to check a box to archive the data. The study therefore focuses on the JSECT, TTU-205, and ECS test sets.

Gathering Data

To conduct a statistical analysis of these support equipment assets as they relate to AA, a 12 month history of each serial numbered asset was compiled from each base. The data used came in the form of "History by Label" reports which were pulled from the PMEL Automated Management System (PAMS). These reports were used because they recorded each maintenance action on every serially tracked tester in the study. Of the six bases selected for the case study, Hill AFB was the only base which did not use the PAMS system to record maintenance actions on testing equipment. For this reason, Hill AFB was omitted from the statistical analysis. The "History by Label" reports were used by mapping out each tester's down time during FY16. This was done by identifying the date each tester was broken out (taken from the Julien date portion of the Job Control Number (JCN) and the date the tester was repaired. That timeframe was blocked out in order to show a period of unavailability. Next, each asset type was then examined to determine its percentage of availability during each month of FY16. The availability percentage is calculated using the formula below.

$$\frac{\#\ of\ equipment\ days\ available}{\#\ of\ items\ authorized * \#\ of\ days\ in\ a\ month}$$

Equipment days available are calculated using the following formula

$$\#\ items\ issued * \#\ days\ per\ month - \#\ days\ when\ each\ item\ was\ unavailable$$

For example, during the month of October 2015, Holloman AFB was authorized five JSECT testers but only had four issued to them. This meant that there were 124 tester days available ($4\ testers * 31\ days\ in\ October = 124\ tester\ days$) of which 50 tester days represent the number of days when a tester was unavailable. The percentage of availability during the month of October for JSECT testers at Holloman therefore is:

$$\frac{(4 * 31) - 50}{5 * 31} = \frac{74}{155} = .4774$$

This calculation is applied to each base, asset type, and month during FY-16 in order to obtain data suitable for statistical analysis.

Aircraft specific data was much easier to gather since it could all be pulled from LIMS-EV in the Weapons System View module. This module provides an à la carte recall of metrics for any aircraft type, time period, theater or a multitude of other filters. LIMS-EV Weapons System View module was therefore used to pull AA, NMC, PMC, 8-hr fix rate, and TAI numbers for the six bases of study during FY-16.

Conclusion

It is clear from the data collection that gathering aircraft specific data is a quick and simple task requiring only a few mouse clicks in LIMS-EV Weapons System View.

In contrast, gathering equipment specific data is much more labor intensive and requires accessing multiple systems which may or may not have the ability to show historical data. An ideal scenario for equipment data collection would be a LIMS-EV Equipment module which mirrors the capabilities of the current LIMS-EV Weapons System View module for aircraft data. Such a capability would eliminate the necessity of this study as a comparison of AA and support equipment could be performed with a few clicks of the mouse. This chapter explains the logic behind case study design, interview process, equipment selection, and gathering of data needed for analysis.

IV. Results

Case Study Results

Each base presented unique circumstances which affected their ability to generate aircraft for flying. Although there were differences between the units in terms of mission, geography, MAJCOM and footprint, there were also similarities which were captured as well. The following paragraphs identify the unique situations, specific challenges, and the recurring theme of issues at each location.

Site 1: Shaw Air Force Base, South Carolina

Shaw Air Force Base was the largest F-16 operation in terms of total aircraft assigned as well as the number of squadrons with 80 F-16s and three combat F-16 units. The goal of this case study was to examine the operations at Shaw AFB to understand the mission and assess which support equipment pieces may be affecting the ability for maintenance personnel to ready the aircraft for flying operations. Aside from this, Shaw AFB acted as the pilot case study and in doing so it acted as a gauge for all interview questions and this location was used to identify personnel of interest at a typical F-16 base who may have information which was of importance to the study. During the visit to Shaw Air Force Base, seven individuals were interviewed including Production Superintendents, Expeditors, an AGE Production Superintendent, and an AGE technician. In addition to these individuals, PMEL supervision, Support Section personnel (equipment custodian), Logistics Readiness Squadron (LRS) Equipment Specialists, and the Maintenance Squadron Commander and Chief Master Sergeant (CMSgt) were also interviewed. After the interviews and subsequent case studies was complete, Shaw seemed to have a unique situation from a number of respects. First, as the only base with three combat F-16 squadrons, Shaw had a larger footprint of support equipment than other bases from an absolute perspective. This meant that they were able to obtain lateral support in the event that a particular piece of equipment assigned to their unit was inoperable, deployed, in calibration, or otherwise unavailable for use. In addition to this, the ability to "Frankenstein" testing equipment together appeared to be a real advantage for maintenance personnel. The idea of "Frankensteining" testers into a working set was common amongst all of the bases which had multiple F-16 units or multiple units on base with common testers. This would happen if one squadron had a working tester CPU but did not have a working set of cables/accessories or vice versa. Shaw AFB was also unique in that an ANG F-16 unit was stationed roughly 30 minutes from their location at McEntire Joint National Guard Base which they utilized from time to time during equipment shortages.

However, one limitation that Shaw AFB had was that as the largest combat unit, they would often deploy one or more squadrons at a time, sometimes to separate locations. This meant that the practice of sharing and "Frankensteining" equipment, which they had come to rely on at home station, was no longer available to them in the deployed location.

Finally, of the seven individuals interviewed, only three mentioned the ECS or 205 testers as being difficult to obtain or unreliable while no interviewees identified the JSECT tester as being difficult to obtain or unreliable.

Site 2: Luke Air Force Base, Arizona

Unlike Shaw AFB, Luke AFB was strictly a pilot training base without a deployment mission. This meant that the aircraft returned to their location every day with the rare exception of depot or other maintenance which took place off station. Maintenance personnel from AGE, flightline and backshop operations were interviewed again for the purpose of capturing the F-16 operations and identifying problem areas which were created or exacerbated by CSE. During the case study visit, Luke AFB was in the process of transitioning from five F-16 units to two F-16 units and three F-35 units. This meant that the footprint of available equipment for F-16 maintenance purposes was lower than it had once been; which can be indicated as a factor which may have contributed to their maintenance and AA metrics. It was also mentioned during the numerous interviews that Luke AFB may be gaining an additional F-16 unit which would be transferred from Hill AFB in Utah.

Luke AFB was unique not only for their flying mission, but also for the fact that there were F-16s located on base which belonged to foreign military operations, namely Singapore. This meant that they had the ability to share equipment with the hosted countries maintenance operation, so long as it was compatible with the U.S. aircraft. One final piece of information which was presented during this case study was that as an AETC base without a combat mission, Luke AFB was able to status and fly aircraft in a PMC condition which would require an NMC status at a combat base. This meant that systems such as Rear Warning Radar (RWR) or other non-flight-critical systems which would need to be troubleshot or tested using specific and hard to obtain testers could be inoperable without grounding the aircraft. This practice had the potential therefore to mask problems with CSE availability and reliability in that AA may not be negatively affected if specific testers were not available.

Finally, of the nine individuals interviewed, three mentioned the JSECT tester as being difficult to obtain or unreliable while four identified the 205 tester and three identified the ECS tester to be difficult to obtain or unreliable.

Site 3: Holloman Air Force Base, New Mexico

Holloman AFB in New Mexico was commonly referred to as “Luke East” during the study because it has the same pilot training mission as Luke AFB in Arizona. The F-16s located here were transferred from Luke AFB in 2014 and 2015 during which time Holloman’s F-22 squadrons were transferred to Tyndall AFB, Florida. Holloman AFB operates two F-16 squadrons in the same manner as Luke AFB in that the aircraft takeoff and return to Holloman AFB every day with the exception of maintenance actions taking place off station. With such similar operations, Holloman AFB was almost identical from a maintenance standpoint when compared to Luke AFB. One notable difference however was the lack of F-16 specific infrastructure and support from a back shop perspective. Many construction projects were underway during my visit in order to better facilitate F-16 maintenance.

Additionally, with the F-16 only recently being transferred to Holloman AFB, not all of the required support equipment was available. For example, while Luke AFB had a compliment of six TTU-205 testers for two squadrons, Holloman AFB only had four for the same aircraft footprint. Maintenance personnel revealed during different interviews that they would often borrow TTU-205 testers from Global Hawk units also stationed at Holloman AFB.

Finally, of the seven individuals interviewed, four identified the JSECT tester as being difficult to obtain or unreliable while three identified the 205 tester to be difficult to obtain or unreliable and another three identified the ECS tester to be difficult to obtain or unreliable.

Site 4: Nellis Air Force Base, Nevada

Nellis AFB in Nevada operates three F-16 units, only two of which were assessed for the purpose of this study. Those two units operated aggressor F-16 operations for Red Flag missions and test F-16s for operational and developmental test missions. The third unit, USAF Thunderbirds, was not assessed due to the unique and limited mission for which they are responsible. Nellis AFB is home to a wide array of aircraft including F-15, F-16, F-22, F-35, and A-10. This benefits the F-16 maintenance operations in that other aircraft units potentially own support equipment which could be used by F-16s if needed.

Nellis AFB was unique in a number of aspects from the diverse aircraft presence to the unique mission of test. One notable difference in Nellis' operations was that all AGE maintenance was performed by contractors instead of traditional AF personnel. However, it was not clear if this operation had any effect on the overall availability of AGE, but it was the only base to rely on contracted AGE maintenance.

Finally, of the 11 individuals interviewed, nine cited the JSECT tester as being difficult to obtain or unreliable while four identified the 205 tester and three identified the ECS tester as being difficult to obtain or unreliable.

Site 5: Hill Air Force Base, Utah

Hill AFB in Utah hosts one F-16 unit, which is slated for transfer to another location due to the bed down of F-35 units. Three other F-16 units had recently been transferred to other locations in the USAF leaving only one F-16 unit at Hill AFB. At the time of the case study visit, many F-16s from the last remaining unit were TDY to Nellis AFB for Red Flag operations. While the vast majority of F-16s had been transferred from Hill AFB, not all of the support equipment assigned to those units had been transferred with them leaving a larger than normal pool of available support equipment assets behind. In addition, Hill AFB was home to the F-16 depot line which had a large assortment of F-16s in various states of repair and upgrade. This meant that additional F-16 specific support equipment was available to flightline maintainers if necessary.

Finally, of the seven individuals interviewed, no interviewees mentioned the JSECT tester as being difficult to obtain or unreliable while only one identified the 205 tester and two identified the ECS tester as being difficult to obtain or unreliable.

Site 6: Eielson Air Force Base, Alaska

Eielson AFB in Fairbanks, Alaska operates a unique F-16 operation from many standpoints. Not only do they operate a small number of F-16s, but they are geographically separated from any other F-16 unit to the greatest extent when compared to all other stateside F-16 units. One particular point of emphasis which was observed during the case study visit was that Eielson does not operate a PMEL laboratory but instead ships all of its assets that require calibration/repair to Elmendorf AFB in Anchorage, Alaska. While this is a relatively short shipment of one day in either direction, it adds a level of complexity to the logistics required to repair or calibrate equipment.

Finally, of the four individuals interviewed, one identified the JSECT tester as being difficult to obtain or unreliable while two identified the 205 tester and only one identified the ECS tester as being difficult to obtain or unreliable.

Interview Results

In addition to the specific support equipment assets which the SMEs felt were of concern or difficult to get/keep in a serviceable condition, two factors presented themselves during interviews with the flightline and AGE personnel. The first factor noted during interviews was the PMEL. Each PMEL is responsible for calibrating and performing limited repair on a wide array of equipment located at their respective base as well as equipment sent to them by agencies outside of the base. Each piece of equipment requiring calibration will receive an initial calibration before it can be used by the unit to which it is assigned. The equipment is calibrated using information found in WEB AFCAV which identifies the specific tests to run as well as the prescribed calibration interval. After the calibration is performed, the equipment is tagged with a calibration label identifying the date of calibration as well as the date when that calibration expires. At that time, the equipment will be entered into PAMS where a complete history of that asset is kept.

The second factor which presented itself during interviews was the practice of sharing and "Frankensteining" equipment in order to obtain a serviceable test set. Test sets such as the JSECT, TTU-205 and ECS are comprised of many components such as the tester itself, a cable set and an accessory set. A successful test of the aircraft requires a fully functional set of all components as any faulty part will render the set unusable. With only a handful of issued test sets in each squadron, the likelihood of having a fully functioning set was low. This meant that maintainers would often rely on sister units or visiting units to provide parts and pieces to make a fully functioning set. This practice was noted at every case study location with Shaw AFB routinely borrowing equipment from a Guard F-16 base which was geographically separated from them by roughly 30 minutes.

Equipment Data

After conducting 45 interviews, the interviewee responses were compiled and each piece of support equipment identified during the interview was recorded. Figure 3 shows the number of interviewees who identified each of the top 10 items as being potentially impactful to aircraft maintenance.

From this list, the top three testers were selected as the basis for statistical testing. Originally the top three AGE assets were also selected to be included for analysis, but a lack of complete and available data made that task impossible given the timeframe of the study. The data system which tracks maintenance actions on AGE assets only retains data for a short period of time (three months) after which it is purged from the system unless the maintainer who inputted the data selects the automated history button at the time of entry.

% Response	Count	CSE Asset
37.8%	17	JSECTS Tester
37.8%	17	MULE
35.6%	16	205 Tester
28.9%	13	ECS Tester
24.4%	11	-60
22.2%	10	128 Tester
22.2%	10	SCNGS
20.0%	9	Boresight Equip
13.3%	6	Wave Guide Pressure Tester
11.1%	5	Borescope

Figure 3: Interviewee Response Matrix

In order to determine if the JSECT, 205, or ECS test sets were predictive of Aircraft Availability, a one year history of each base was collected for each of the testers assigned to F-16 units. That data came in the form of *History By Label* reports which were pulled by each base's PMEL laboratory from the PAMS system. Each report showed both the JCN containing the Julian date when the tester was broken out and the job completion date which showed when the tester was fixed. These dates were mapped out for all of FY-16 to show when each tester was out of service. Figure 4 shows a sample mapping for September 2016 at Holloman AFB.

Base	Asset Type	Asset SN	1-Sep-16	2-Sep-16	3-Sep-16	4-Sep-16	5-Sep-16	6-Sep-16	7-Sep-16	8-Sep-16	9-Sep-16	10-Sep-16	11-Sep-16	12-Sep-16	13-Sep-16	14-Sep-16	15-Sep-16
Holloman	205 Tester	TV133															
Holloman	205 Tester	1815	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL							
Holloman	ECS Tester	728	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	
Holloman	ECS Tester	816															
Holloman	JSECTS	362														PMEL	PMEL
Holloman	JSECTS	472	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL						
Holloman	JSECTS	451	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL
Holloman	JSECTS	441								PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL

Base	Asset Type	Asset SN	16-Sep-16	17-Sep-16	18-Sep-16	19-Sep-16	20-Sep-16	21-Sep-16	22-Sep-16	23-Sep-16	24-Sep-16	25-Sep-16	26-Sep-16	27-Sep-16	28-Sep-16	29-Sep-16	30-Sep-16
Holloman	205 Tester	TV133															
Holloman	205 Tester	1815															
Holloman	ECS Tester	728															
Holloman	ECS Tester	816															
Holloman	JSECTS	362	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL								
Holloman	JSECTS	472															
Holloman	JSECTS	451	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL	PMEL			
Holloman	JSECTS	441	PMEL														

Figure 4: Equipment Availability Mapping

After mapping out all of the testers, the availability percentage for each tester at that base was calculated for each month using the formula:

$$\frac{\#\ testers\ assigned * (\#\ days\ in\ the\ month - \#\ days\ when\ tester\ was\ not\ available)}{\#\ testers\ authorized * \#days\ in\ the\ month}$$

In addition to the tester availability percentage, the number of testers sent to PMEL each month as well as the average duration of repair/calibration was also calculated to capture the tester's reliability and reparability. Figure 5 shows the above calculations at Holloman AFB for the entirety of FY16.

Month	JSECT	ECS	205	#JSECT Sent to PMEL	# ECS Sent to PMEL	# 205 Sent to PMEL	Avg JSECT PMEL Turn Time	Avg ECS PMEL Turn Time	Avg 205 PMEL Turn Time
January	0.232258065	0.403225806	0.403225806	3	1	1	12	12	12
February	0.510344828	0.206896552	0.353448276	3	3	0	14	11.33333333	0
March	0.741935484	0.427419355	0.5	1	1	0	9	9	0
April	0.78	0.491666667	0.391666667	1	1	1	3	1	13
May	0.6	0.411290323	0.5	1	3	0	31	3.666666667	0
June	0.6	0.5	0.375	1	0	1	15	15	15
July	0.709677419	0.5	0.193548387	1	0	2	14	0	19
August	0.425806452	0.25	0.25	2	2	1	29	15.5	31
September	0.44	0.383333333	0.433333333	4	0	2	13.5	0	11
October	0.477419355	0.467741935	0.5	2	0	1	25	0	4
November	0.553333333	0.3	0.5	3	1	0	12	24	0
December	0.4	0.5	0.35483871	2	0	1	31	0	18

Figure 5: Calculated Tester Variables Example

Four additional variables were thought to be predictive of AA and were added to the data set for analysis. These included a seasonal component in the form of monthly dummy variables in JMP, TAI (Total Active Inventory) which represented the number of F-16s assigned to each base, the assigned aircraft block numbers at each base, and the average age of aircraft at each base. The TAI, assigned block numbers, and average age were pulled from the LIMS-EV Weapons System View module. Figure 6 shows all of the evaluated variables.

Variable
JSECT % Available
JSECT # to PMEL
JSECT PMEL Turn Time
ECS % Available
ECS # to PMEL
ECS PMEL Turn Time
TTU-205 % Available
TTU-205 # to PMEL
TTU-205 PMEL Turn Time
TAI
Monthly Dummy Variable
AC Block Numbers
Avg Age of Aircraft

Figure 6: List of Variables

Although Aircraft Availability is the primary focus of this study, lower level metrics were also included into the analysis as they have the potential to be impacted by support equipment. These metrics are MC rate, NMC rate, PMC rate, and 8-hr fix rate, all of which were pulled from LIMS-EV Weapons System View.

Analysis

Aircraft Availability

The first test performed on data was a one way analysis and Tukey-Kramer test between bases and AA. Figure 7 shows that Eielson AFB has a significantly higher range of AA with the lowest point being higher than the highest point at all other bases.

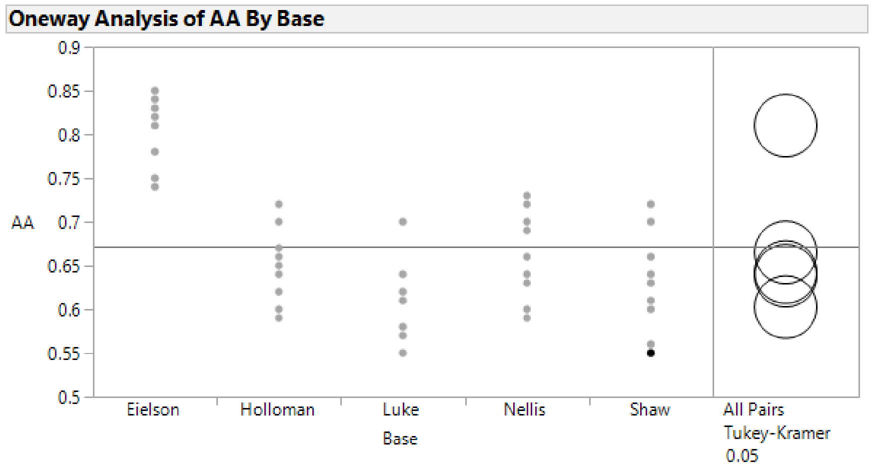


Figure 7: One Way AA by Base

The results from this test meant that the five bases could not be treated as one population but would instead need to be treated as two distinct populations. Using a blocking scheme to separate Eielson from the rest of the bases, a stepwise analysis was executed using a P-value threshold stopping rule and a mixed direction for variables entering and exiting the model. The P-value to enter the model was set at .05 with the probability to leave set at .1. The resulting model created from this analysis identified aircraft block numbers as the most predictive with very low P-values (see Figure 8). One tester variable, JSECT # to PMEL, was identified in this model but it was insignificant when compared to the aircraft block number coefficients. This model did have a relatively high adjusted R^2 of .768 however but due to the insignificance of the tester variable it was not explored further.

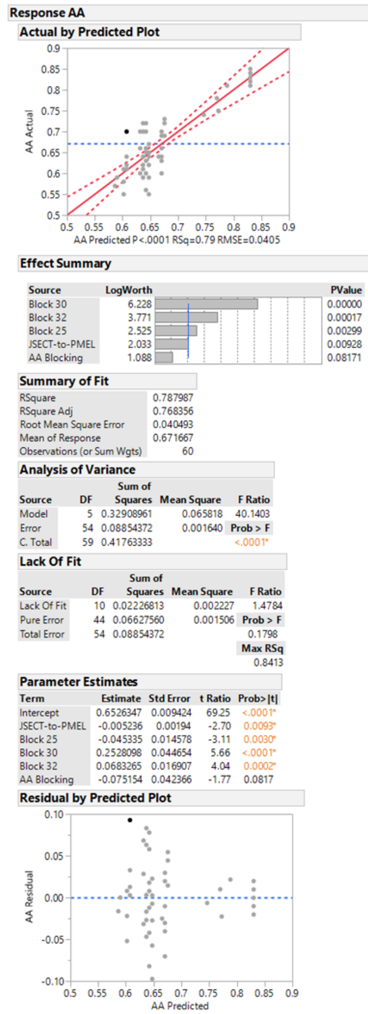


Figure 8: AA Model

Mission Capable

The next analysis was conducted in the same manner as the AA analysis but MC was used for the response variable. After performing a one way analysis to include the Tukey-Kramer test, it was apparent that thee distinct populations existed which would need to be blocked before performing further analysis (see Figure 9). The blocking scheme used for this test was with Eielson AFB as one set, Shaw AFB as a second set, and Nellis AFB, Luke AFB, and Holloman AFB as a third set.

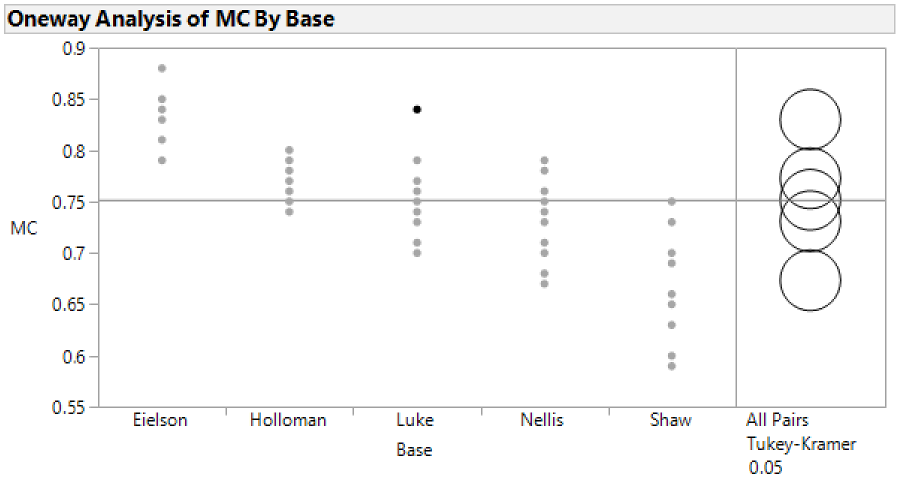
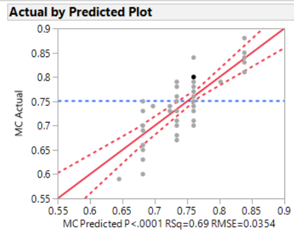


Figure 9: One Way MC by Base

A stepwise analysis was executed on MC using the same settings as the test for AA with similar results (see Figure 10). While the adjusted R^2 value of .678 showed that the chosen model fit fairly well, the variables identified by the analysis were Block 32 aircraft and August. The lack of any tester variables entering into this model again meant that no further exploration of this model was undertaken.

Response MC

Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue
MC/NMC Blocking	14.634	0.00000
Block 32	1.575	0.02658
August	1.516	0.03051

Summary of Fit

RSquare	0.694771
RSquare Adj	0.67842
Root Mean Square Error	0.035424
Mean of Response	0.751667
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.15995951	0.053320	42.4897
Error	56	0.07027383	0.001255	Prob > F
C. Total	59	0.23023333		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	4	0.00613292	0.001533	1.2430
Pure Error	52	0.06414091	0.001233	Prob > F
Total Error	56	0.07027383		0.3043
				Max RSq
				0.7214

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.6032689	0.015401	39.17	<.0001*
August	-0.036727	0.016547	-2.22	0.0305*
Block 32	-0.026042	0.011433	-2.28	0.0266*
MC/NMC Blocking	0.0783333	0.007231	10.83	<.0001*

Residual by Predicted Plot

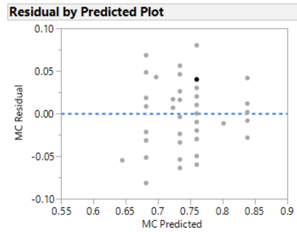


Figure 10: MC Model

Partially Mission Capable

Like the previous two analyses, a one way analysis of the variable against all five bases revealed that Holloman AFB was significantly different than the other bases in terms of average PMC (see figure 11). A blocking scheme was created to separate Holloman AFB from the other four bases before a stepwise analysis was performed.

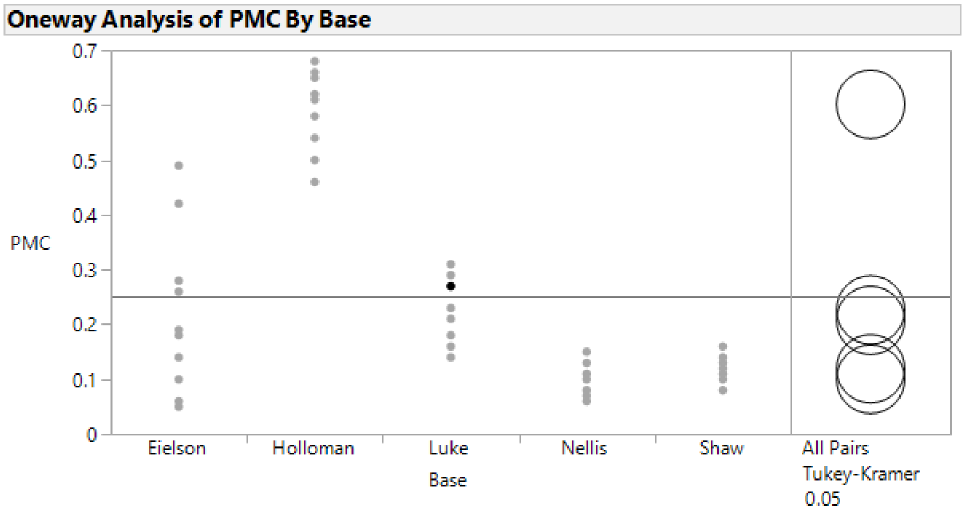
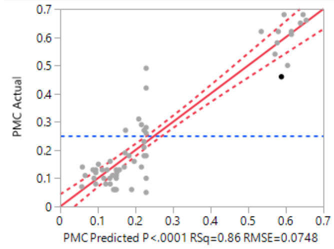


Figure 11: One Way PMC by Base

The stepwise analysis was performed for PMC using the same settings as the previous tests for AA and MC. This test returned a model which had the highest adjusted R^2 of any tests performed to this point and included the JSECT % available variable as well as the average aircraft age variable (see Figure 12). Since this model included a variable related to the testers of interest and its coefficient was significant, further diagnostics of the model were performed. In order to validate the model, the assumptions of constant variance, normality, and independence were tested. The first check performed on the model was to ensure that none of the selected variables were overly influential to the model by checking the Variance Inflation Factor (VIF) scores associated with each variable for multicollinearity.

Response PMC

Actual by Predicted Plot



Effect Summary

Source	LogWorth	PValue
PMC BLocking	23.217	0.00000
JSECTS %Availabile	3.328	0.00047
Average AC Age	1.635	0.02317

Summary of Fit

RSquare	0.864281
RSquare Adj	0.857011
Root Mean Square Error	0.074841
Mean of Response	0.251
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	1.9974754	0.665825	118.8728
Error	56	0.3136646	0.005601	Prob > F
C. Total	59	2.3111400		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	38	0.13723129	0.003611	0.3684
Pure Error	18	0.17643333	0.009802	Prob > F
Total Error	56	0.31366462		0.9953
				Max RSq
				0.9237

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|	VIF
Intercept	-0.25462	0.099685	-2.55	0.0134*	.
JSECTS %Availabile	0.2182914	0.058758	3.72	0.0005*	1.5521613
Average AC Age	0.0088586	0.003794	2.33	0.0232*	1.1075659
PMC BLocking	0.4979461	0.029049	17.14	<.0001*	1.4462729

Residual by Predicted Plot

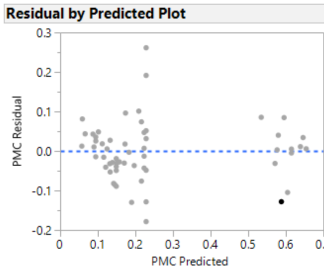


Figure 12: PMC Model

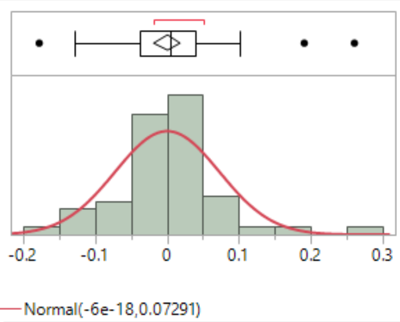
Since none of the points were higher than 5, it was determined that no multicollinearity existed in the model. Constant variance was then checked using the Breusch-Pagan test which returned a P-value of .0035 indicating that constant variance did not exist (see Figure 13).

n	60
df	3
SSE	0.3136646
SSM	0.00074102
TS	13.55724424
P-Value	0.003574175

Figure 13: Breusch-Pagan Result

Normality was then checked by performing a Shapiro-Wilk test for goodness of fit against the residuals saved from the model. Figure 14 shows the results of this test with a P-value of.0195 indicating that the distribution was not normally distributed. A visual check of the data indicated that while the Shapiro-Wilk P-value indicated a failure, visually the data seemed to be normally distributed.

Residual PMC



Fitted Normal

Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	μ	-5.55e-18	-0.018836	0.0188355
Dispersion	σ	0.0729133	0.0618038	0.0889296

-2log(Likelihood) = -144.94548002948

Goodness-of-Fit Test

Shapiro-Wilk W Test

W	Prob<W
0.952076	0.0195*

Note: Ho = The data is from the Normal distribution. Small p-values reject Ho.

Figure 14: PMC Residual Distribution

The last test performed on the model was to check for independence using the Durbin-Watson test on the residuals of the model. Figure 15 shows the results of this test and with a P-value of less than .0001, the test for independence did not pass. The results from these tests show that although a high adjusted R^2 was generated for the model, it was not selected for use since it did not pass diagnostic tests for constant variance, normality or independence.

Durbin-Watson

Durbin-Watson	Number of Obs.	AutoCorrelation	Prob<DW
1.0627324	60	0.4417	<.0001*

Figure 15: PMC Durbin-Watson

Not Mission Capable

To test whether NMC was at all predictable by the variables included in this research, a one way analysis was used as the starting point to see if the bases could be treated as one population or if a blocking factor needed to be applied. Figure 16 shows the one way analysis with Tukey-Kramer pairings applied. The results from this test show that three distinct populations existed and blocking factors were created to account for the differences.

With the blocking factor applied, a stepwise analysis was performed with NMC as the response variable. Figure 17 shows the results of the stepwise analysis which did not identify any tester variables as predictive which meant that this model was not examined further.

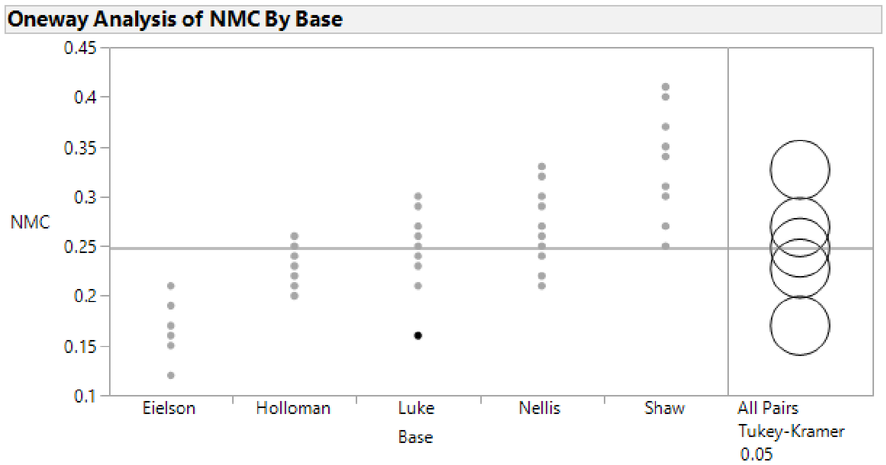


Figure 16: One Way NMC by Base

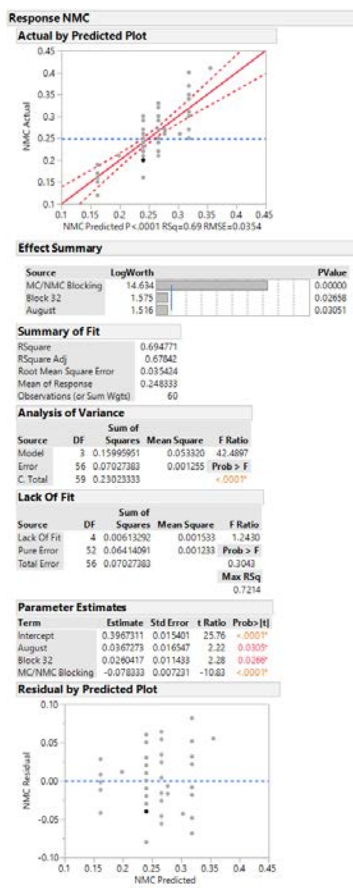


Figure 17: NMC Model

8-Hr Fix Rate

The final response variable to be examined was the 8-hr fix rate which began with the same one way analysis shown in Figure 18. Unlike the other metrics examined, the 8-hr fix rate did not require a blocking factor in order to test for predictive variables. A stepwise analysis was executed against the 8-hr fix rate with poor results. Figure 19 shows that no tester variables were chosen in the selected model with only two months being identified as predictive but with an adjusted R^2 value of .281 indicating a very poor model. This model was therefore not explored further.

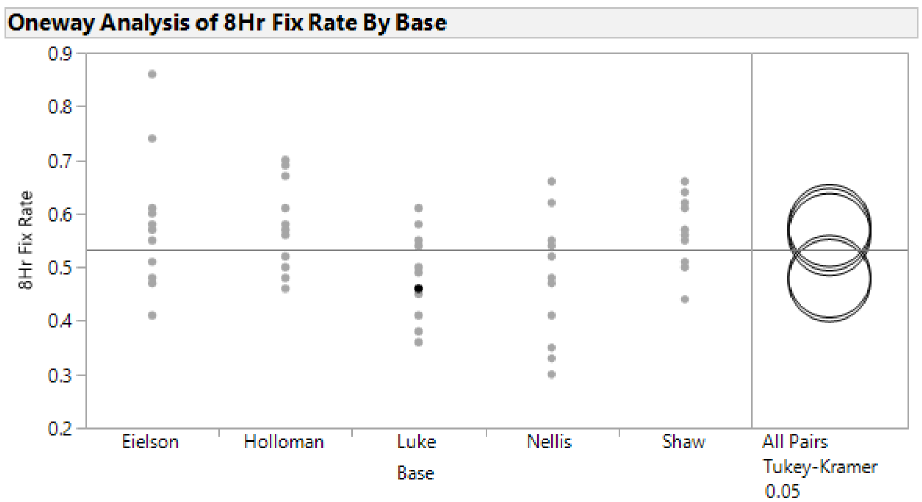
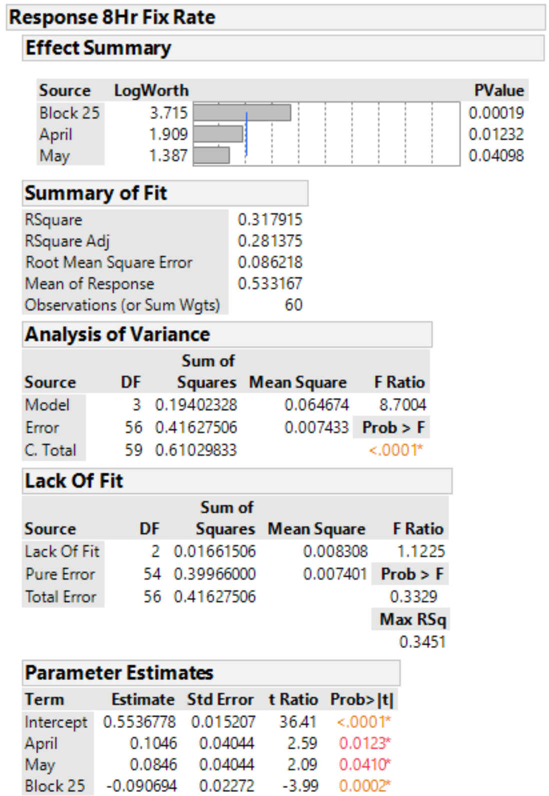


Figure 18: One Way 8-Hr Fix Rate by Base



Response 8Hr Fix Rate

Effect Summary

Source	LogWorth	PValue
Block 25	3.715	0.00019
April	1.909	0.01232
May	1.387	0.04098

Summary of Fit

RSquare	0.317915
RSquare Adj	0.281375
Root Mean Square Error	0.086218
Mean of Response	0.533167
Observations (or Sum Wgts)	60

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	3	0.19402328	0.064674	8.7004
Error	56	0.41627506	0.007433	Prob > F
C. Total	59	0.61029833		<.0001*

Lack Of Fit

Source	DF	Sum of Squares	Mean Square	F Ratio
Lack Of Fit	2	0.01661506	0.008308	1.1225
Pure Error	54	0.39966000	0.007401	Prob > F
Total Error	56	0.41627506		0.3329
				Max RSq
				0.3451

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.5536778	0.015207	36.41	<.0001*
April	0.1046	0.04044	2.59	0.0123*
May	0.0846	0.04044	2.09	0.0410*
Block 25	-0.090694	0.02272	-3.99	0.0002*

Figure 19: 8-Hr Fix Rate Model

Lag-1 Variables

An additional set of scenarios considered in this research was that AA is being affected by the previous month's tester variables or that a current month's AA was predictable by the previous month's AA. These scenarios were explored through the use of a Lag-1 variable for AA and each of the nine tester variables. These were added to the data set in JMP and a fit model was run against each of the response variable considered. The results of this Lag-1 analysis was that each model produced was predictable primarily by the previous month's AA. Some of the Lag-1 variables and some of the original variables would occasionally enter into the models, but their coefficients were so low that they were not considered to be significant to the model and the models were therefore not explored further.

Analysis Summary

After examining the variables against each of the five metrics it is clear that none of the variables examined are predictive. Although the PMC metric seemed to be predictable by at least one tester variable, it failed all tests levied against it and was therefore abandoned. The result of these tests therefore is that none of the variables included in the research are predictive of AA, MC, PMC, NMC, or 8-hr fix rate for stateside Active Duty F-16s during FY-16.

Summary of Findings

While no statistical significance was found between any of the chosen predictor variables and the examined response variables, the limitations of this study meant that only a small fraction of the equipment needed to support a very limited subset of the Air Force's fighter fleet could be studied. Additionally, given that the period of time included in this research was only one year, it is feasible that the equipment examined may have had significant impact before or after the window of study. Further limiting the scope of this research are the maintenance data systems used to track support equipment. From the original list of possible equipment candidates for research, six were chosen for further study but three of those items were removed due to a lack of necessary data. The remaining three support equipment items were only able to be studied because the precise calibration requirement levied upon them meant that a robust data system was in place and was able to provide the necessary data for analysis. If such a system were to exist for all support equipment, this research would have included more items for analysis and different conclusions may have been reached.

Although the quantitative portion of this research did not reveal any significant link between CSE and AA, the qualitative portion may reveal the reason. During the 45 interviews at five bases, a recurring theme was present when it came to testers and similar support equipment. The practice of borrowing equipment in whole or in part from other units on base, visiting units, or even units at nearby bases was common amongst all maintenance units. This "Frankensteining" of equipment, as it was often referred to, enabled maintainers to get the job done and ready the aircraft even if they did not possess the equipment necessary to do so. While this undoubtedly lead to more sorties and a healthy fleet, it may also have led to a masking of problems with support equipment by not allowing the mission to fail.

V. Conclusion and Recommendations

Chapter Overview

This chapter summarizes the research accomplished in the preceding section and discusses the outcomes related to the questions proposed in the introduction. It also highlights recommendations for future research.

Problem Statement and Research Questions

AA is being negatively impacted by a CSE fleet which has become less reliable than designed even though the current number of CSE assets available are above the authorized levels. In order to explore this problem, a set of research questions were compiled which sought to quantify the AA and CSE relationship and capture maintenance practices which may explain the relationship qualitatively. The research questions guiding this research were:

1. What impact does common support equipment (CSE) have on Aircraft Availability?
2. What statistical relationship best describes how CSE authorizations and levels affect aircraft availability?
3. What LIMS-EV Equipment View shortfalls limit CSE focus and management?
4. What MX work-arounds mask the impact of CSE on aircraft availability?

From a quantifiable standpoint, this research did not uncover any impact that CSE has on AA. All of the analyses performed showed factors such as aircraft block number, geographic location, or previous month's AA as being predictive of AA but no tester variables were shown to be predictive. Anecdotally the story is much different however as many interviewees stated that they knew CSE was impactful to AA but those same interviewees would later comment that they would beg, borrow, and steal in order to get CSE required to fix an aircraft rather than let that aircraft remain unrepaired.

Question two was not able to be explored quantifiably as it is derived from question one. If a working model would have been uncovered where on hand and authorized levels could have been manipulated, then a quantifiable answer may have been given for this question. Qualitatively however, each base identified the need for more equipment and higher authorizations. Although the CSE identified as being short differed from base to base, the interviewees almost always identified the same equipment as being difficult to obtain/unreliable as well as needing an increased authorization.

Answering question three may offer one of the largest takeaways from this research. The lack of a robust equipment maintenance tracking system severely limited this research and necessitated multiple data pull request from each of the bases involved in the research. Additionally, the limitations of IMDS meant that half of the equipment selected for study was eliminated before any analysis could be performed as the data necessary for analysis was not available. If these underlying systems were in place, or were redesigned such that maintenance information inputted into them was kept for long periods of time as a default, then a LIMS-EV Equipment module could be built to pull from those systems and aggregate the data in a user friendly way similar to the LIMS-EV Weapons System View module. Current practices to manage enterprise wide pools of equipment are severely handicapped by these anemic data systems.

The final question offers the other large takeaway from this research and may be the reason why no quantifiable relationship could be established between CSE and AA. The maintenance mentality of “make it happen” or “solve for yes” means that maintainers routinely go to extraordinary lengths to ensure that the mission does not fail. While these efforts are indeed laudable from an aircraft readiness standpoint, they mask the true state of CSE and may do more harm than good. The heroics involved in making the mission happen often require maintainers to borrow equipment from sister units, TDY units who are visiting their base, foreign service units stationed at their base, non F-16 units on their base, and even units from other components at other bases in close proximity. This “Frankensteining” of equipment as it was often referred to, was identified at all six bases during the case studies. Even if the equipment was not able to be cobbled together from multiple units, some CSE shortfalls were masked by the maintenance unit carrying a PMC condition on their aircraft. Pilot training units for example could be without a working JSECTS tester but still keep their aircraft flying because the system calibrated by the tester was not needed for pilot training. As an example, one of the two units at Holloman AFB had 22 of 25 aircraft assigned to them in a PMC condition due to an unavailability of JSECTS at the time of the case study. At a combat unit, the same condition would be highlighted as the 22 aircraft may not be considered available, but at Holloman AFB, no decrease to AA was recorded during this time.

Recommendations for Future Research

Capturing sufficient data was a severe limitation to this research and as such the pool of equipment studied was cut in half. A future research opportunity on this same topic would be a long term study of one location with a stand-alone data recording scheme. If Shaw AFB were selected, for example, a research protocol could be developed where usage tracking sheets were assigned to multiple pieces of equipment for a six month period. Since Shaw AFB was included in this research, the same six pieces of equipment could be selected for study thereby eliminating the need for equipment selection research. Maintainers who used the equipment would need to record the date and time that each piece of equipment was attached to an aircraft for use as well as the time it was removed. The maintainer would also record the aircraft tail number and performance of the piece of equipment such as whether the equipment worked without flaw or if problems occurred. Additionally, backshop repair functions would also need to record when the piece of equipment entered into repair or service actions, what the action was and whether it was schedule or unscheduled. A longitudinal study of this nature would allow researchers to track the movements of multiple pieces of equipment across one base to see how often they were used, how they functioned, and how often they were sent to repair. This would allow for a better picture of the heroics involved in accomplishing the mission which may not be captured through traditional maintenance tracking programs.

In addition to the limited data available from the CSE perspective, this research was also limited in that it focused only on F-16s from active duty bases in CONUS. An additional recommendation for future research is to repeat the study with a different airframe, a different USAF component, or in a different location. The factors identified by interviewees as important or of interest for this research may be different depending on the aircraft platform, component of service, or geographic location. Aircraft like the F-22 or F-35 for example would be prime candidates for a parallel study as they do not share common tester equipment with other aircraft and would therefore not benefit from other non-F-22/35 units on base as an additional equipment resource.

Appendix A. Interview Protocol

CONSENT TO PARTICIPATE IN INTERVIEW

DISTRIBUTION OF AIRMEN TIME RESEARCH

You have been asked to participate in a research study conducted by researchers from the Air Force Institute of Technology (AFIT), Graduate School of Engineering and Management, Department of Operational Sciences. The main objective of the project is to determine the impact of Common Support Equipment (CSE) on Aircraft Availability. The results of this interview will be included in a report and briefing to AFMC/A4M, as well as a thesis defense. You were selected as a possible participant in this study because of your knowledge, experience, and first-hand account of the tasks of interest. You should read the information below and ask questions about anything you do not understand before deciding whether or not to participate.

- This interview is voluntary.
- You will not be compensated for participating in this interview.
- The information you tell us will be kept confidential.
- Data collection for this project will be completed by December 2016. All survey documents will be stored in a secure work space until 1 year after that date. The documents will then be destroyed.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

Name of Subject:

Signature of Subject ______________________________________ Date ____________

Signature of Investigator ___________________________________ Date ____________

Please contact Dr. Johnson with any questions or concerns at alan.johnson@afit.edu or 937-255-3636 x4703.

Interview Questions

1) Which CSE items are most scarce/highly sought after?
2) Which CSE items are least reliable?
3) How confident are you that these CSE items will work when used?
4) How does sharing these assets affect your ability to use them?
5) What would you do if this piece of equipment was not available?
6) How often do you call for/need each piece of equipment?
7) What pieces of CSE overlap in their purposes?
8) Which one is the primary and which is the secondary?
9) How does CSE affect NMCM?
10) How would a classification of NMCM-CSE effect your reporting?
11) How do you track CSE status?
12) How could CSE status tracking be improved?
13) What database do you input tracking data into?
14) What are your current levels of CSE compared to your authorizations?

Appendix B. IRB Exemption Letter

DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE OF TECHNOLOGY
WRIGHT-PATTERSON AIR FORCE BASE OHIO

9 August 2016

MEMORANDUM FOR DR. ALAN JOHNSON

FROM: Jeffrey A. Ogden, Ph.D.
AFIT Exemption Determination Official
2950 Hobson Way
Wright-Patterson AFB, OH 45433-7765

SUBJECT: Approval for exemption request from human experimentation requirements (32 CFR 219, DoDD 3216.2 and AFI 40-402) for the Common Support Equipment Study

Your request was based on the Code of Federal Regulations, title 32, part 219, section 101, paragraph (b) (2) Research activities that involve the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior unless: (i) Information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) Any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.

1. Your study qualifies for this exemption because you are not collecting sensitive data, which could reasonably damage the subjects' financial standing, employability, or reputation. Further, the demographic data you are collecting, if any, and the way that you plan to report it cannot realistically be expected to map a given response to a specific subject.

2. This determination pertains only to the Federal, Department of Defense, and Air Force regulations that govern the use of human subjects in research. Further, if a subject's future response reasonably places them at risk of criminal or civil liability or is damaging to their financial standing, employability, or reputation, you are required to file an adverse event report with this office immediately.

11/15/2016

X Jeffrey A. Ogden

Jeffrey A. Ogden, Ph.D.
IRB Exempt Determination Official
Signed by: OGDEN.JEFFREY.A.1292682030

Appendix C. Raw Data

Month	Base	JSECT	ECS	205	AA	MC	NMC	PMC	8Hr Fix Rate	Aircraft Units Assigned	TAI	#JSECT Sent to PMEL	# ECS Sent to PMEL	# 205 Sent to PMEL	Avg JSECT PMEL Turn Time	Avg ECS PMEL Turn Time	Avg 205 PMEL Turn Time
Jan	Shaw	0.774	0.417	1.022	0.63	0.66	0.34	0.13	0.62	3	81	2	1	6	28.00	31.00	9.00
Feb	Shaw	0.871	0.405	1.118	0.66	0.7	0.3	0.16	0.51	3	80.6	2	2	3	15.00	16.50	5.67
Mar	Shaw	0.532	0.363	1.156	0.7	0.73	0.27	0.14	0.64	3	80	4	3	1	31.50	17.00	4.00
Apr	Shaw	0.696	0.400	1.144	0.7	0.73	0.27	0.12	0.56	3	80	3	2	2	24.33	18.00	11.00
May	Shaw	0.871	0.360	0.941	0.72	0.75	0.25	0.08	0.66	3	80	2	2	4	16.00	26.00	21.00
Jun	Shaw	0.867	0.367	0.897	0.64	0.69	0.31	0.1	0.51	3	80	3	3	4	10.67	16.00	24.25
Jul	Shaw	0.899	0.323	0.844	0.63	0.65	0.35	0.11	0.5	3	80	2	4	5	12.50	16.50	24.00
Aug	Shaw	0.952	0.352	0.831	0.56	0.59	0.41	0.12	0.57	3	80	2	3	8	6.00	18.33	15.63
Sep	Shaw	0.983	0.386	1.019	0.55	0.6	0.4	0.13	0.44	3	80	1	4	5	4.00	10.25	10.60
Oct	Shaw	0.661	0.465	0.997	0.61	0.65	0.35	0.13	0.56	3	81	3	1	4	27.67	12.00	15.50
Nov	Shaw	0.567	0.408	1.150	0.66	0.7	0.3	0.11	0.55	3	81	4	2	2	26.00	16.50	3.00
Dec	Shaw	0.673	0.411	1.148	0.6	0.63	0.37	0.1	0.61	3	81	4	1	2	20.25	2.00	19.00
Jan	Luke	1.000	1.008	0.973	0.61	0.79	0.21	0.21	0.54	2	53	0	4	1	0.00	15.25	5.00
Feb	Luke	0.879	1.405	0.989	0.55	0.71	0.29	0.16	0.5	2	53	1	2	1	7.00	5.50	2.00
Mar	Luke	0.935	1.371	0.731	0.58	0.77	0.23	0.31	0.55	2	53	1	1	4	4.00	16.00	12.50
Apr	Luke	0.817	1.367	0.850	0.58	0.75	0.25	0.18	0.46	2	53	1	2	4	11.00	8.00	6.75
May	Luke	0.968	1.194	0.903	0.61	0.74	0.26	0.14	0.45	2	53	1	2	2	2.00	19.00	9.00
Jun	Luke	1.000	1.492	1.000	0.62	0.75	0.25	0.18	0.38	2	53	0	1	0	0.00	1.00	0.00
Jul	Luke	1.000	1.315	0.694	0.7	0.84	0.16	0.27	0.46	2	53	0	2	6	0.00	11.00	9.50
Aug	Luke	0.774	1.226	0.919	0.61	0.73	0.27	0.27	0.41	2	53	1	2	2	14.00	16.50	7.50
Sep	Luke	1.000	1.500	1.000	0.64	0.76	0.24	0.27	0.58	2	53	0	0	0	0.00	0.00	0.00
Oct	Luke	0.968	1.355	0.978	0.61	0.73	0.27	0.29	0.49	2	53	1	3	1	2.00	6.00	4.00
Nov	Luke	1.000	1.375	0.983	0.55	0.7	0.3	0.21	0.61	2	53	1	1	1	1.00	15.00	2.00
Dec	Luke	1.000	1.258	0.742	0.57	0.75	0.25	0.23	0.36	2	53	4	3	0	12.00	10.00	0.00
Jan	Holloman	0.232	0.403	0.403	0.62	0.79	0.21	0.62	0.58	2	55	3	1	1	12.00	12.00	12.00
Feb	Holloman	0.510	0.207	0.353	0.59	0.75	0.25	0.68	0.5	2	55	3	3	0	14.00	11.33	0.00

Mar	Holloman	0.742	0.427	0.500	0.62	0.78	0.22	0.68	0.7	2	55	1	1	0	9.00	9.00	0.00
Apr	Holloman	0.780	0.492	0.392	0.59	0.75	0.25	0.66	0.69	2	55	1	1	1	3.00	1.00	13.00
May	Holloman	0.600	0.411	0.500	0.65	0.79	0.21	0.62	0.67	2	55	1	3	0	31.00	3.67	0.00
Jun	Holloman	0.600	0.500	0.375	0.64	0.77	0.23	0.61	0.52	2	55	1	0	1	15.00	15.00	15.00
Jul	Holloman	0.710	0.500	0.194	0.67	0.8	0.2	0.65	0.46	2	55	1	0	2	14.00	0.00	19.00
Aug	Holloman	0.426	0.250	0.250	0.65	0.74	0.26	0.58	0.56	2	55	2	2	1	29.00	15.50	31.00
Sep	Holloman	0.440	0.383	0.433	0.66	0.76	0.24	0.62	0.5	2	55	4	0	2	13.50	0.00	11.00
Oct	Holloman	0.477	0.468	0.500	0.7	0.8	0.2	0.46	0.48	2	56	2	0	1	25.00	0.00	4.00
Nov	Holloman	0.553	0.300	0.500	0.72	0.8	0.2	0.5	0.61	2	55.8	3	1	0	12.00	24.00	0.00
Dec	Holloman	0.400	0.500	0.355	0.6	0.74	0.26	0.54	0.57	2	55	2	0	1	31.00	0.00	18.00
Jan	Nellis	0.532	0.460	0.761	0.66	0.75	0.25	0.15	0.48	3	60	1	2	2	0.00	0.00	18.50
Feb	Nellis	0.638	0.509	0.655	0.69	0.76	0.24	0.13	0.62	3	59.7	1	3	3	13.00	9.33	16.67
Mar	Nellis	0.750	0.750	0.903	0.69	0.73	0.27	0.13	0.47	3	59	0	0	1	0.00	0.00	15.00
Apr	Nellis	0.750	0.750	0.953	0.72	0.78	0.22	0.1	0.54	3	59	0	0	1	0.00	0.00	7.00
May	Nellis	0.750	0.452	0.955	0.73	0.79	0.21	0.11	0.66	3	59	0	3	1	0.00	12.33	7.00
Jun	Nellis	0.733	0.750	0.967	0.64	0.71	0.29	0.06	0.35	3	59	1	0	2	0.00	0.00	0.00
Jul	Nellis	0.597	0.750	0.748	0.63	0.7	0.3	0.1	0.52	3	59	1	0	2	19.00	0.00	19.50
Aug	Nellis	0.621	0.460	0.877	0.7	0.74	0.26	0.08	0.47	3	59	1	3	2	16.00	12.00	9.50
Sep	Nellis	0.750	0.633	0.940	0.69	0.73	0.27	0.06	0.41	3	59	0	1	1	0.00	14.00	9.00
Oct	Nellis	0.500	0.556	0.800	0.64	0.73	0.27	0.13	0.33	3	60	2	2	2	18.00	9.50	8.00
Nov	Nellis	0.500	0.675	0.660	0.6	0.67	0.33	0.08	0.55	3	60	1	1	3	30.00	9.00	17.00
Dec	Nellis	0.331	0.734	0.800	0.59	0.68	0.32	0.07	0.3	3	60	2	1	1	26.00	2.00	31.00
Jan	Eielson	1.000	0.720	1.000	0.82	0.84	0.16	0.05	0.51	1	21	0	0	0	0.00	1.00	0.00
Feb	Eielson	0.603	0.805	0.931	0.78	0.81	0.19	0.06	0.41	1	21	11.5	8.5	4	2.00	2.00	1.00
Mar	Eielson	0.823	0.839	1.000	0.75	0.81	0.19	0.06	0.55	1	21	11	15	0	1.00	1.00	0.00
Apr	Eielson	1.000	0.822	1.000	0.85	0.85	0.15	0.26	0.86	1	21	0	16	0	0.00	1.00	0.00
May	Eielson	1.000	0.581	0.806	0.83	0.84	0.16	0.49	0.57	1	21	0	19.5	12	0.00	2.00	1.00
Jun	Eielson	1.000	0.667	1.000	0.81	0.81	0.19	0.42	0.61	1	21	0	0	0	0.00	1.00	0.00
Jul	Eielson	1.000	0.882	1.000	0.81	0.84	0.16	0.28	0.47	1	21	0	11	0	0.00	1.00	0.00
Aug	Eielson	0.742	0.570	0.790	0.74	0.79	0.21	0.19	0.58	1	21	16	16	5	1.00	3.00	1.00
Sep	Eielson	0.733	0.700	0.750	0.81	0.81	0.19	0.14	0.55	1	21	8	27	0	2.00	1.00	0.00
Oct	Eielson	1.000	1.000	1.000	0.83	0.83	0.17	0.26	0.48	1	21	0	0	0	0.00	0.00	0.00
Nov	Eielson	1.000	0.922	0.767	0.84	0.85	0.15	0.18	0.6	1	21	0	7	14	0.00	1.00	1.00
Dec	Eielson	1.000	1.000	1.000	0.85	0.88	0.12	0.1	0.74	1	21	0	0	0	0.00	0.00	0.00

Appendix D. Quad Chart

Common Support Equipment and Its Impact on Aircraft Availability

Capt Jason Leighton
Advisor: Dr. Alan Johnson
Department of Operational Sciences (ENS)
Air Force Institute of Technology

Problem Statement

Aircraft Availability (AA) is being negatively impacted by a Common Support Equipment fleet which has become less reliable than designed even though the current number of Common Support Equipment (CSE) assets available are above the authorized levels.

Research Questions

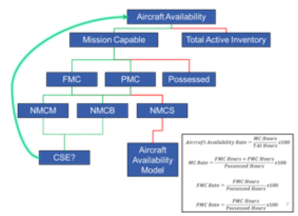
- *What impact does common support equipment (CSE) have on Aircraft Availability?*
- *What statistical relationship best describes how CSE authorizations and levels affect aircraft availability?*
- *What LIMS-EV Equipment View shortfalls limit CSE focus and management?*
- *What MX work-arounds mask the impact of CSE on aircraft availability?*

Methodology

Step 1: Interviews
- Interviewed SMEs from 6 F-16 bases to determine equipment of interest for statistical analysis

Step 2: Data Collection
- Pulled maintenance history for each equipment item being studied at each base for FY-16

Step 3: Analysis
- Compared JSECT, TTU-205, and ECS tester maintenance histories to AA, MC, NMC, PMC, 8-hour fix rate



%	Count	Equipment	Equipment
37.8%	17	JSECTS Tester	Joint Service Electronic Combat Test System
37.8%	17	MULE	Hydraulic Test Stand
35.6%	16	205 Tester	Avionics System Tester
28.9%	13	ECS Tester	Environmental Control System Tester
24.4%	11	-60	Electric Generator
22.2%	10	128 Tester	Generator Output
22.2%	10	SCNGS	Self Containted Nitrogen Generation System
20.0%	9	Boresight Equip	
13.3%	6	Wave Guid Pressure Tester	
11.1%	5	Borescope	

Sponsor
AFMC/A4M & A4P
Col Scott Fike

Regression Analysis

RESULTS

Quantitative

- No variables of interest predictive of to AA, MC, NMC, PMC, 8-hour fix rate

Qualitative results

- No statistical link between CSE and AA possibly because of:
  - Units Share Equipment With
    - Sister units
    - Visiting TDY units
    - Non F-16 units
    - GSUs
    - Foreign Service Units
  - Make working test set from multiple non-working sets
  - Never let the mission fail

  Database Shortcomings
  - IMDS requires maintainers choice for historical record
  - No single data system for CSE
  - Different MDSs use different field level MX systems
  - LIMS-EV Equipment View not capable of showing individual equipment status/quantity

FUTURE RESEARCH

- Longitudinal Case Study
  - Limit study to one base with high level of researcher involvement
  - Track equipment during one year
  - Put data recording tool in place for selected equipment
  - Overcome IMDS shortcomings/ maintenance heroics

Department of Operational Sciences

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
23-03-2017	Master's Thesis	Sep 2015 - Mar 2017

4. TITLE AND SUBTITLE

Common Support Equipment and its Impact on Aircraft Availability

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Leighton, Jason M., Capt, USAF

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

AFIT-ENS-MS-17-M-141

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

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10. SPONSOR/MONITOR'S ACRONYM(S)

AFMC/A4M & A4P

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

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14. ABSTRACT

The ability of military aircraft maintenance personnel to prepare aircraft for flight depends not only on the technical ability and availability of replacement parts, but also on access to serviceable support equipment. While the general relationship between support equipment failures and aircraft availability is understood, the struggle to quantify that relationship makes targeted support equipment replacement or quantity authorization increases difficult. Tight budgets and aging equipment further complicate the task of keeping serviceable support equipment assets in the hands of maintainers. We identify key pieces of support equipment which may affect aircraft availability and other metrics and investigate the associated relationships in a case study of the F-16 aircraft.

15. SUBJECT TERMS

Common Support Equipment, Aircraft Availability

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Dr. Alan Johnson, AFIT/ENC
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